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ABSTRACT

The assertion that girls and boys in single-sex schools outperform their peers attending coeducational schools was investigated in this study with particular reference to physics achievement. The relationship between the school, the home and the student's performance in physics was also explored tentatively using multilevel analysis. The average home background (called the socioeducational level in this study) was found to contribute towards student achievement to a greater extent when compared with such school effects as school type and the sex composition of the school. The importance of the use of the multilevel model in estimating microparameters such as sex differences as well as macroparameters such as school type, is illustrated in this study by the significant influence of the school aggregate variable, socioeducational level. This is a preliminary report describing some of the school and home effects influencing student performance using multilevel statistical methodology. A list of 28 references is included. (Author)

Sex Differences in Science Achievement: A Multilevel Analysis

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Introduction

The relationship between student achievement in science and socioeducational factors, such as home background and school environment has been the subject of a great deal of interest in the school effectiveness debate. In particular, the common claim of enhanced achievement of students attending single-sex schools is the subject of this paper. While there is a perception that student performance is enhanced within the independent single-sex school, little concrete evidence has been provided that this is the case. When student achievement in single-sex and coeducational schools has been compared, studies often neglect to account for other factors such as home background and attitudes. In a recent article, Jones (1990) pointed out the importance of parental income, parental education, subject choices and teacher attitudes impacting on student achievement. In this study, parental occupation and education and the number of books in the home were combined into a single measure termed socioeducational level.

The gradual merging of single-sex schools into coeducational schools is taking place in America, Britain and Australia with little discussion by the general community of educators. Coeducation is considered by some educators and parents to be more equitable and to represent the real world in which girls and boys will have to spend their future lives (Willis & Kenway, 1986), although this view has been challenged by other researchers such as Sarah, Scott and Spender (1980), Rossiter (1982), Howe (1984), Mahony (1985), Rowe (1988) and Jones (1990).

Steedman's (1983) findings of higher science achievement of girls in single-sex schools than coeducational schools and higher science achievement of boys in coeducational schools than single-sex schools in England conflicts with research by Lee and Bryk (1986) in the United States and Carpenter and Hayden (1987) in Australia. The latter researchers found that girls and boys attending private single-sex schools had significantly higher academic achievement than students attending government coeducational schools. However, the research available is often confounded by socioeconomic factors and the school environment. Educational researchers often fail to adequately address the fact that single-sex schools are often private and have higher socioeconomic groups of students attending them. The higher achievement of students in the single-sex schools could be simply an artefact of the higher performance of students from upper class backgrounds attending private schools.

The purpose of this study was to use secondary analysis of a large Australian database known as the Second International Science Study to examine the role of student, school and home factors in explaining student differences in science achievement and attitudes, particularly the single-sex school environment. Although sex differences in science achievement have been investigated in previous large scale studies (Keeves, 1973; Comber & Keeves, 1973; Kelly, 1978), these researchers did not account for the stratification of the sample by state and school type (government, Catholic and independent) and the multilevel nature of the data consisting of students nested within schools. A distinctive methodological feature of the present research is that it employed methodology which accommodated both the complex sample design and the multilevel nature of the data. This paper presents some results of a multilevel analysis of the Second International Science Study, revealing the strength of the socioeducational level measure in predicting student performance irrespective of the school type.

Second International Science Study

Data for this study was obtained from the Australian database of the Second International Science Study, a cross-country study of science achievement, student attitudes, teacher characteristics and school environment. This large database provided a wide range of variables and a stratified sample design not normally possible in ordinary survey analysis. The Second International Science Study was undertaken during 1980 to 1984 to provide an overview of science education across 24 countries (data collected in 1983). Although more than eight years old, the data still provide the largest reliable source of science education information available in Australia. It was designed to provide a basis for informed debate about the nature and content of school science education that would best suit the needs of the students and societies to which they belong. The study was conducted under the auspices of the International Association for the Evaluation of Educational Achievement (IEA) in association with educational research institutes in each country.

In the Second International Science Study, only multiple-choice items were used, rather than written or open-ended questions and practical laboratory based exercises. It was possible that these types of items could have been biased favouring those types of students who do well on questions which require selection, rather than production, of a response from the student without prompting. There has also been some suggestion that multiple-choice items may be biased in favour of male students, when compared with female students (Harding, 1979; Murphy, 1982; Murphy, 1988; Bolger & Kellaghan, 1990; Mazzeo, Schmitt & Bleistein, 1991). Drawing inferences from this type of science test item may not be valid, if science achievement is usually assessed using a mixture of multiple choice, open-ended or other types of questions.

Instrumentation and Methodology

The measure of science achievement used in this analysis was physics achievement and consisted of eight multiple choice test items. In previous analyses of this database, sex differences were found to be greatest for physics achievement, than for biology or chemistry achievement (Young 1991), with boys appearing to outscore girls in physics subtests.

There were 4917 14-year-old students in this sample (2565 girls and 2352 boys) selected from 233 schools. The target population of 14-year-old Australian students consisted of 246,132 students within 2144 schools at the time of this survey (1983/84). The sample design used in this study was a stratified two-stage cluster design, with schools selected randomly from within each of 24 strata (consisting of the eight Australian states and territories and the three school types: government, Catholic and independent) and students selected randomly from within each school. This complex sample design meant that the normal assumptions of simple random sampling could not be made in order to test statistical significance. For this reason, a multilevel model was developed which accounted for the nested nature of the data. In addition, students in each strata were weighted according to the proportion of students they were supposed to represent.

Sex Differences in Single-sex and Coeducational Schools

Initially, student performance in physics achievement was compared by school type and sex in order to establish the size of school type and gender differences in mean achievement. While males significantly outperformed females, these differences were found to be greater for coeducational schools, when standard errors and sample design were accounted for (Table 1a). Although the mean sex difference in physics achievement was 8.15 percent for single-sex schools and 5.12 percent for coeducational schools, it is likely that these figures did not represent the true sex differences. The differences in standard errors between the two school types meant that the mean physics achievements were not comparable without adjustments for larger standard errors found in complex sample designs (in this case a stratified two-stage cluster sample design).

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Table 1a. Sex Differences in Physics Achievement by Sex Composition of the School for 14-year-old Students.

Sex Composition of School	Male Mean %	Male N	Female Mean %	Female N	M-F Mean Difference %	M-F Mean Diff Effect Size	M-F Ratio SRS*	M-F Ratio Complex*
Single-sex	70.86	581	62.71	426	8.15	0.28	3.11	1.61
Coeducational	67.11	1977	61.99	1919	5.12	0.18	3.93	2.03

* Ratio stands for the ratio of male-female mean difference and 2 standard errors of difference.
Ratio is statistically significant at the 0.05 level of confidence if ratio is ≥ 1.00 or ≤ -1.00.

Table 1b. School Type Differences in Physics Achievement by Sex for 14-year-old Students.

Sex	Single-sex - Coeducational Mean Difference	Ratio SRS*	Ratio Complex*
Males	3.75	1.75	0.91
Females	0.72	0.36	0.19

* Ratio stands for the ratio of male-female mean difference and 2 standard errors of difference.
Ratio is statistically significant at the 0.05 level of confidence if ratio is ≥ 1.00 or ≤ -1.00.

The male/female ratio (complex) was divided by 2 standard errors (adjusted for the complex sample design using the Design Effect (Kish, 1965) calculated using the bootstrap technique as described by Efron (1982) as follows:

$$\text{M-F Ratio Complex} = \frac{\text{(Male Mean - Female Mean)}}{2\ \mathrm{se}(\bar{x}_C)}$$

The sampling design used in this study was a stratified two-stage cluster sampling with equal probabilities and without replacement. The estimation of standard errors and confidence intervals of statistics for the complex sample design used in the Second International Science Study was attempted by the IEA in Hamburg using the Jackknife technique (sampling at the school level only). In this study, the Bootstrap was used as an alternative, due to its greater dependability in estimating error (Efron, 1979).

Tukey (1958) and Quenouille (1956) developed the Jackknife method of calculating the sampling error in order to reduce the bias of estimates of means and other statistical parameters. This technique involves the estimation of parameters on the total sample of data and then dividing the sample into groups. Smaller samples are created by omitting one group from each of the samples in turn. The Bootstrap has been described as a more efficient version of resampling with replacement from the observed values (Efron, 1979, 1982), although much more demanding in terms of computer time and disk space. Diaconis and Efron (1983) described the computerised bootstrap, without the assumptions of the Gaussian (normal) distribution of data, as a means of estimating the statistical accuracy of an estimate from the data in a single sample. Samples are generated from the data in the original sample. The name bootstrap is derived from the old saying 'to pull yourself up by your bootstraps' and reflects the fact that the one available sample is used to generate many other pseudosamples.

Tables 1a and 1b present male and female mean physics achievement percentage scores, the male/female difference divided by 2 standard errors (ordinary standard errors are the Simple Random Sample method used by most educational researchers, while the Complex Sample method requires preliminary adjustment of the standard errors). The male/female difference ratio was significant indicating that sex differences existed in single-sex and coeducational schools (Table 1a). When students in single-sex and coeducational schools were compared, male students attending single-sex schools appeared to outperform male students attending coeducational schools by 3.75 percent (Table 1b). However, this difference in achievement was not found to be statistically significant. This school effect did not seem to influence female students to the same extent (0.72 percent), with no statistically significant differences noted between females attending single-sex and coeducational schools.

In summary, while there appeared to be statistically significant sex differences in physics achievement in both single-sex and coeducational schools, the enhanced performance of students attending single-sex schools was not significant when the complex sample design was accounted for.

An Explanatory Model of Physics Achievement: Multilevel Analysis

The conceptual model for this study examined some possible variables which may contribute towards student performance in physics, namely, home background, school characteristics, student ability, sex of the student and student attitudes towards science. However, the main focus of this paper is to examine the association between sex composition of the school (single-sex versus coeducational) and physics achievement.

Most educational research revolves around students who receive schooling in classrooms located within schools, within school districts, within states, etc. The grouping of students, classes and schools occurs in a hierarchical order with each group influencing the members of the group in thought and behaviour. The nature of these hierarchical structures produces multilevel data. If the school effects are ignored when comparing students, then the problem of biased significance tests will lead to erroneous results and inferences (Raudenbush & Bryk, 1986; Raudenbush, 1988). The analysis of unexplained variance in student performance must first be partitioned into the school and student level components, if this bias is to be avoided. In a previous study (Young, 1991) it was found that the school effect ranged from 9 to 19 percent of the total unexplained variance in physics achievement, depending upon the age of the student. If not removed from the statistical analysis, this effect could have led to the underestimation of the standard error resulting in the rejection of the null hypothesis. For example, the finding of statistically significant sex differences could be attributable to the underestimation of the standard error. It is imperative, therefore, that the total amount of variance is estimated using a multilevel model approach. This study employed the use of the Hierarchical Linear Model (HLM) (Raudenbush, 1988) and the computer program developed by Bryk, Raudenbush, Seltzer and Congdon (1989) for these types of analyses.

In this study, examination of the sex differences in physics achievement revealed that the size of sex differences varied with socioeducational level (a measure of socioeconomic status consisting of the parents' occupation and education), school type (government, Catholic and independent) and sex composition of the school (single-sex and coeducational). Sex differences appeared to be greatest at higher socioeducational levels and in government coeducational schools. For this reason, multilevel analysis was performed on the dependent variable of physics achievement. The independent variables found to be associated with statistically significant sex differences in physics achievement were analysed further along with school-level predictors such as the average socioeducational level within the school, whether the school is private or government, whether the school is single-sex or coeducational, the rurality of the school, the average attitudes towards school and science, the average verbal and quantitative abilities of students within the school and the average student perceptions of science teaching strategies within the school.

Because school effects on student performance are multilevel in nature, standard regressions are inadequate and misleading, and usually underestimate the effects of the school and overestimate student characteristics such as sex differences. The multilevel model consists of a separate between-school regression equation for each β coefficient in the regression model. The Hierarchical Linear Model (Raudenbush, 1988; Raudenbush & Bryk, 1986) was used in this study to investigate the effect of the social class of the school and the school organisation (in terms of the average socioeducational level of students in the school, school type and sex composition of the school), as well as the average verbal and quantitative ability of students in the school, on the physics achievement of students in the school. The multilevel analysis was conducted using physics achievement as the student outcome (dependent) variable, in an attempt to explain these student differences in physics achievement. Figure 1 presents a proposed explanatory model including the student characteristics and school effects investigated in this study.

Total Variance of the Dependent Variables

The initial stage in multilevel analysis involved the estimation of the total variance of the dependent variable, physics achievement. The total variance was then further decomposed into between-school and between-student variance as reported in the following sections, in order to determine the source of variations in physics achievement. The independent variables examined included socioeducational level, sex, attitude towards science, verbal ability of the student (a word knowledge test) and mathematical ability of the student (a quantitative measure developed for this study).

The socioeducational level scale was developed by factor analysis of a set of home background items and consisted of the father's occupation (mother's occupation was found to be statistically unsuitable due to being skewed towards home duties), father's secondary education, mother's secondary education, father's post-secondary education, mother's post-secondary education and number of books in the home.

When variance in physics achievement subtest scores among 14-year-old student population, the percentage of explained variance in physics achievement within school was 88.2 percent and between schools was 11.8 percent (see Table 2). The next stage in this investigation involved the analysis of student level variables which could reduce the amount of unexplained within schools variance.

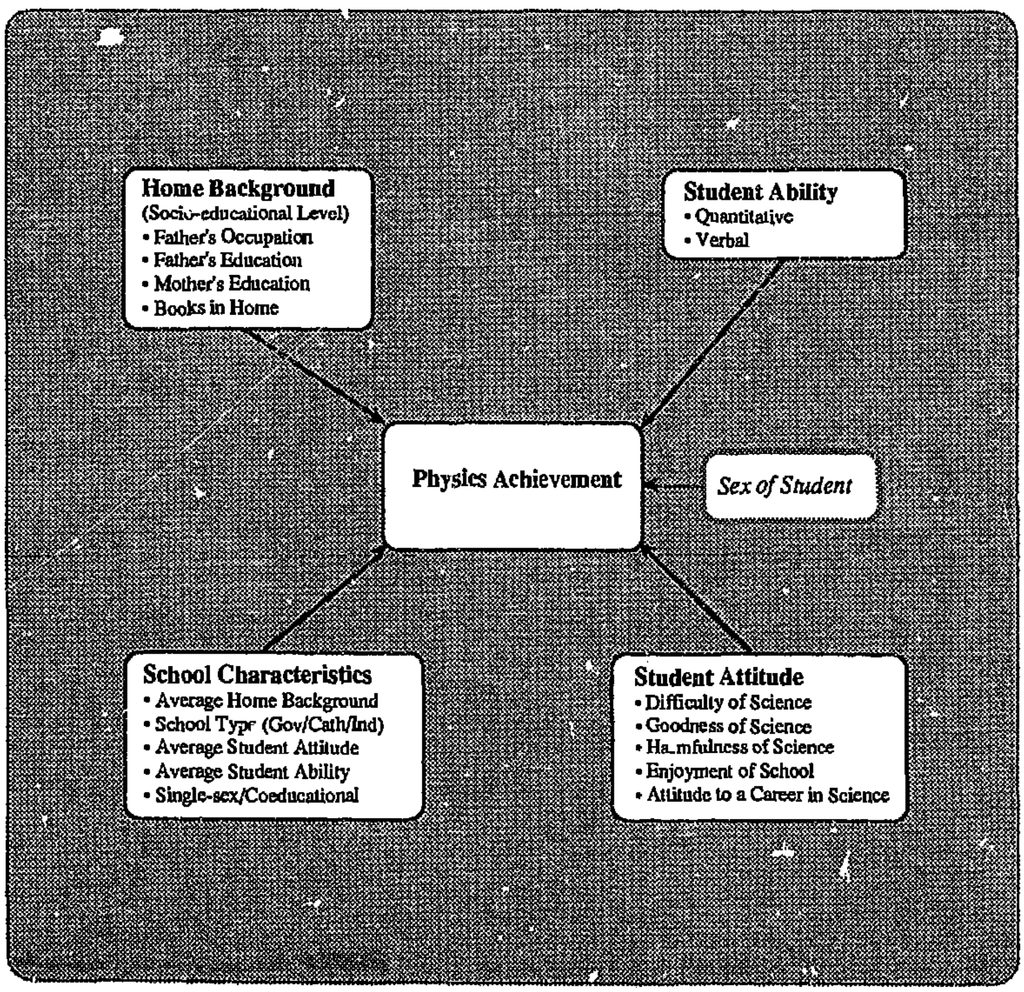

Figure 1 Model for Sex Differences in Science Achievement, Home Background, Student Ability, Student Attitudes and School Characteristics.

Table 2. Variance components using multilevel analysis for physics achievement subtests.

Physics Subtest Dependent Variable	Within Schools Variance	Between Schools Variance
No independent variables	370.24 (88.2%)	49.99 (11.8%)
Student Variables		
Sex, Attitude, Ability	269.2 (27%)	55.05
School Variables		
Sex composition of school	269.2	51.20 (7%)
School Type (Government/Catholic/Ind)	269.2	46.73 (15%)
Sex Composition and School Type	269.2	46.95 (15%)
Socioeducational Level	269.2	32.61 (41%)
Socioeducational Level, Sex Comp, School Type	269.2	32.92 (40%)
Socioeducational Level, School Type	269.2	32.74 (41%)

N.B. Sel = Socioeducational Level (a composite of six home background variables: Father's occupation, Father's secondary education, Mother's secondary education. Father's post-secondary education, Mother's post-secondary education and Number of books in the home).

A model of student achievement which could explain some of the residual variance in physics achievement was investigated including sex of the student, socioeducational level, attitude towards science and a measure of student ability (quantitative). When this model was applied to the data from 14-year-old students, socioeducational level and verbal ability were found not to be significant contributors towards the explanatory model. The estimated within-schools variance for the model was 269.2 (Table 2). This model explained 27 percent of the total within-schools variance (370.24, Table 2).

A more detailed examination of the student level variables found to best fit the explanatory model of physics achievement is found in Table 3 (Section 1, Student Level Variables only). It is readily observed that the beta coefficients are statistically significant, with the intercept and the quantitative ability coefficients having the greater effects. All three student level variables are significant in explaining student performance in physics achievement. The estimated parameter variances for each of these indicates that the sex effect varies from school to school, while the intercept varies greatly from school to school. Further investigations were then made into school level variables which may explain some of this variance.

Sex Composition of School Model

As the sex composition of the school variable has two possible categories, namely, single-sex and coeducational schools, effect coding was used as described in Pedhazur (1982, p. 289). This variable was included in order to attempt to explain student differences in science achievement in terms of one aspect of the school environment, namely, the sex composition of the school.

Although student level variables reduced the amount of unexplained variance in physics achievement, the inclusion of the school effects also contributed somewhat towards explaining between school differences (Table 2). The school effect under initial investigation was the sex composition of the school. When sex composition of the school variable was introduced into the explanatory model, the between schools variance was reduced marginally (7 percent). However, when school type was added, there was a more substantial reduction in between schools variance (15 percent). It did not appear to make any significant difference whether or not sex composition of the school was included with school type. This would appear to indicate that it was the type of school which confounded the results.

When the average socioeducational level of students within the school (an aggregate variable) was included in the model, the drop in unexplained between-schools variance was even more dramatic (41 percent). This variable appeared to swamp the effects of sex composition of the school and school type, with the inclusion of the later not significantly reducing the unexplained between schools variance any further. These results would suggest that it is not the type of school or sex composition of the school which influences student performance in physics, but rather the average socioeconomic status of the students attending the school. Further, when the school effects were examined more closely in Table 3 (Section 2, Student and School Level Variables), the socioeducational level aggregate was found to have a statistically significant effect on student performance.

These results suggest that, while students attending single-sex schools in Australia have outperformed students attending coeducational schools, the increased physics achievement of such students may be due to factors such as the home background of students attending single-sex schools (who also tend to be students from higher socioeconomic groups and attending private schools). The sex of the student, attitudes towards science and quantitative ability were found to contribute towards this model of physics achievement.

Discussion

Multilevel analyses of the Second International Science Study database has revealed a significant school effect, the average socioeducational level (home background) of the students attending the school, which appears to contribute towards enhanced student achievement. This study compared the physics achievement of males and females in single-sex and coeducational schools and indicates that previous research showing statistically significant sex differences in some schools may not have fully accounted for school effects confounding the explanatory model (Comber & Keeves 1973; Lee & Bryk, 1986).

This paper has briefly described one part of a major study involving the Second International Science Study Australian database. In this study, the complex sample design was accounted for by use of weighting and the hierarchical nature of the database was also investigated using multilevel analysis in order to decompose variance into student and school level.

The finding of school level effects on student performance has implications for all educational researchers interested in improving science achievement amongst Australian students. Whether or not the school is single-sex is only one of the school effects which may influence student achievement in science and the sex differences found in physics achievement. It would appear from this study that other school effects confound this variable, such as the average home background of the students attending the school. Further research into these school effects could supply a more complete picture of student performance in science.

Table 3. Explanatory Model of Student and School Effects on Physics Achievement.

1. Student Level Variables Only

		Gamma, γ	Standard Error	t Statistic	P - Value
For Base,	β_0				
Base		64.65	.53	121.255	.000
For Sex,	β_1				
Base		5.86	.65	9.031	.000
For Goodsci,	β_2				
Base		5.10	.61	8.405	.000
For Tot2q,	β_3				
Base		2.50	.07	33.803	.000

Random Parameter	Estimated Parameter Variance	Degrees of Freedom	Chi Square	P - Value
Base	55.05	199	1014.4	.000
Sex	22.30	199	262.45	.002
Goodsci	5.51	199	247.44	.011
Tot2q	.17	199	226.61	.087

2. Student and School Level Variables

		Gamma, γ	Standard Error	t Statistic	P - Value
For Base,	β_0				
Base		65.51	.55	118.867	.000
Socio-educational Level		21.62	1.87	11.567	.000
Private school		.10	.74	.132	.896
Single-sex		-.70	.69	-1.007	.314
For Sex,	β_1				
Base		5.82	.65	8.989	.000
For Goodsci,	β_2				
Base		5.09	.61	8.395	.000
For Tot2q,	β_3				
Base		2.50	.07	33.860	.000

Random Parameter	Estimated Parameter Variance	Degrees of Freedom	Chi Square	P - Value
Base	32.92	196	717.88	.000
Sex	22.04	199	262.50	.002
Goodsci	5.52	199	247.35	.011
Tot2q	.16	199	226.53	.088

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